An introduction to

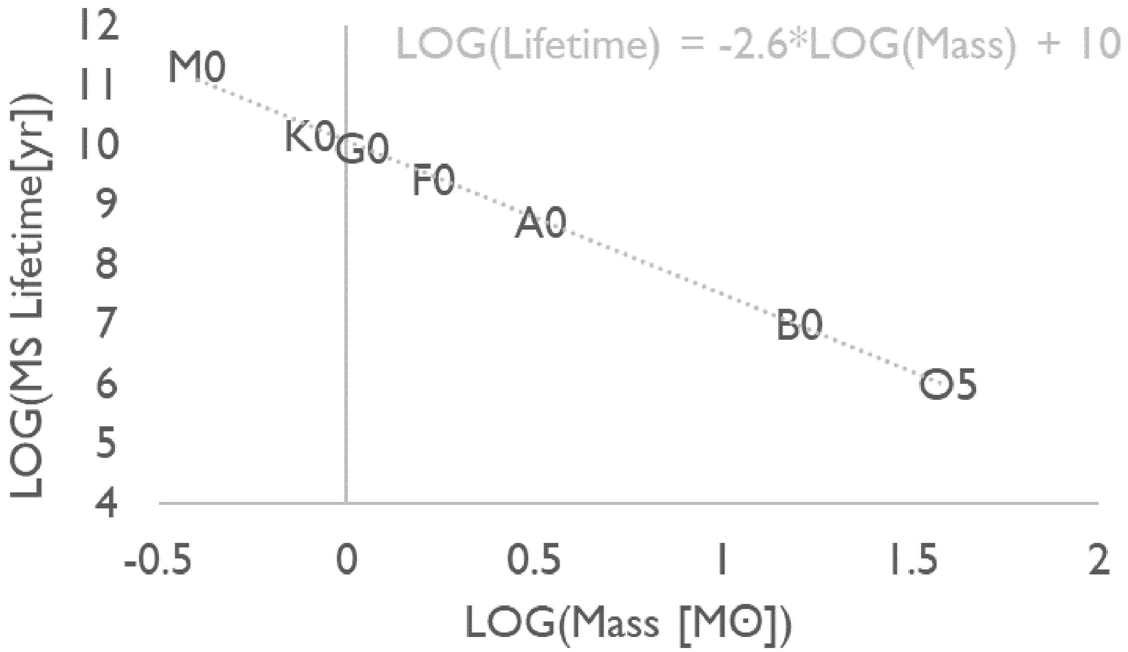
Low Mass Stellar Evolution

Zach Meisel

Ohio University - ASTR1000

Core hydrogen burning doesn't last forever

- Eventually, a star will consume all of the hydrogen in the core
- The lifetime on the main sequence depends on:
  - How much fuel there is to burn (M)
  - The rate at which fuel is burned (L)
- Since $L \propto M^4$ (see Introduction to HR diagram) and the time for burning is the amount of fuel divided by the rate: $\tau = \frac{M}{L}$, then $\tau \propto M^{-3}$, which can be calibrated to the main sequence lifetime of the sun (10Gyr)

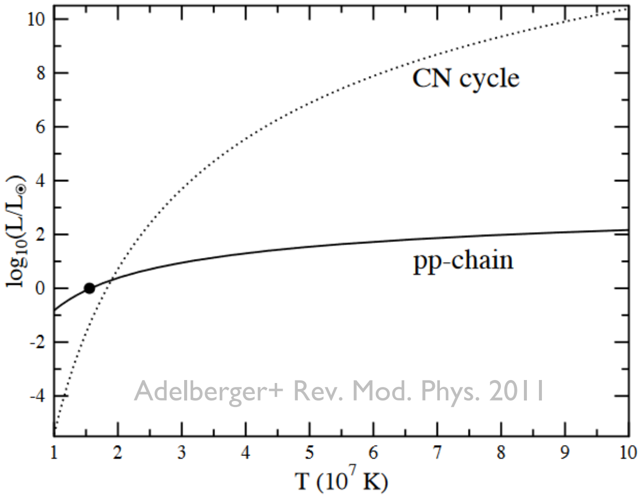


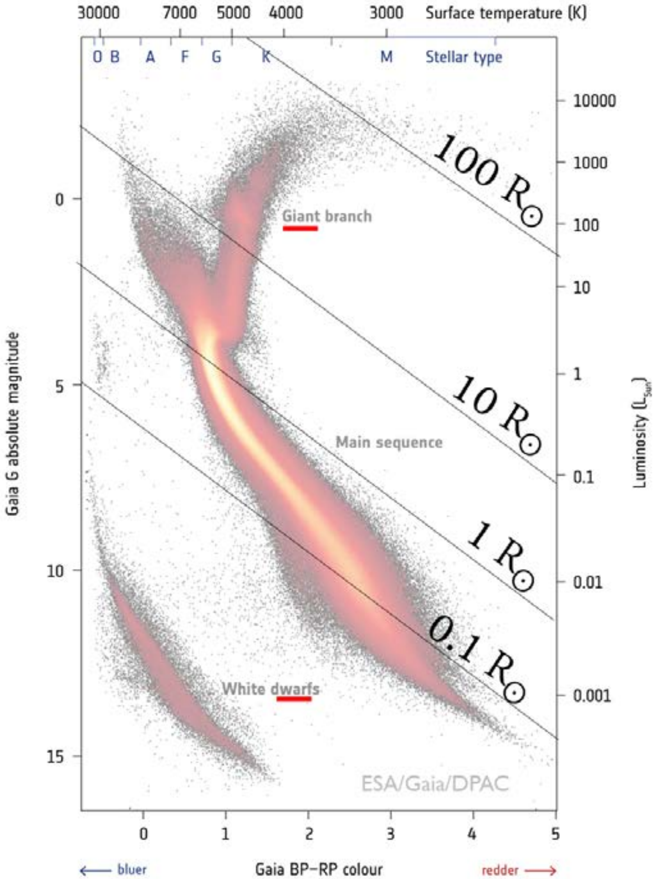
- Empirically, it turns out that $\tau \approx 10 \left(\frac{M}{M_{\odot}}\right)^{-2.6}$ Gyr
  - Eg. an O5 star at 40 $M_{\odot}$ will take, $10*(40)^{-2.6}$ Gyr ~ 7e-4 Gyr ~ 0.7 Myr to consume all hydrogen in its core

Shell hydrogen burning

1. When core H runs out, the core (now made of He) steadily contracts and heats up
2. The H shell around the core can burn, releasing a lot of energy and adding He to the core
3. Because this shell H requires higher temperatures to burn, **the star's luminosity increases**
   (see Introduction to Stellar Nuclear Power)
4. Increased luminosity causes the outer layers to puff-up, **increasing the stellar radius** and therefore lowering the blackbody temperature. So, **the star becomes redder**

- This is how a **"Red Giant"** is made
  and explains its location on the HR-diagram
- Because of the higher luminosity and reduced amount of fuel, the time spent on the RGB is ~10% or less of the MS lifetime

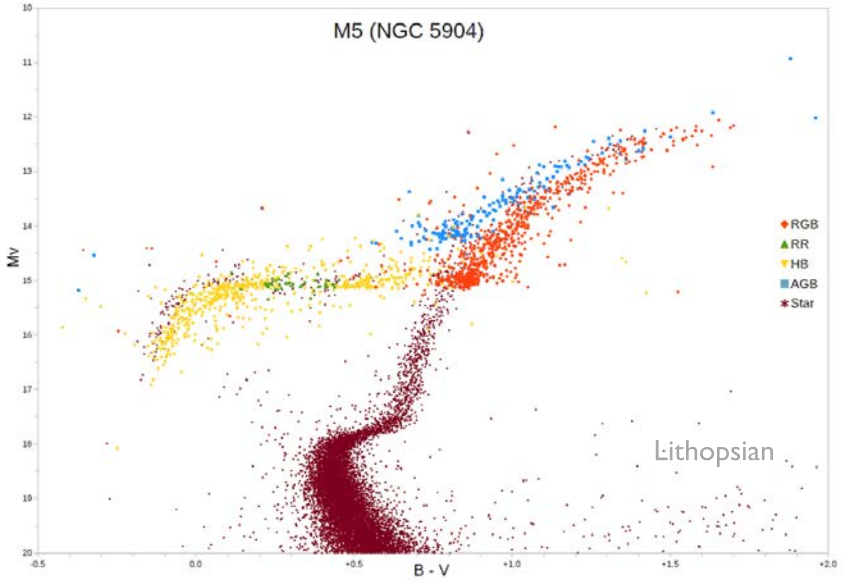


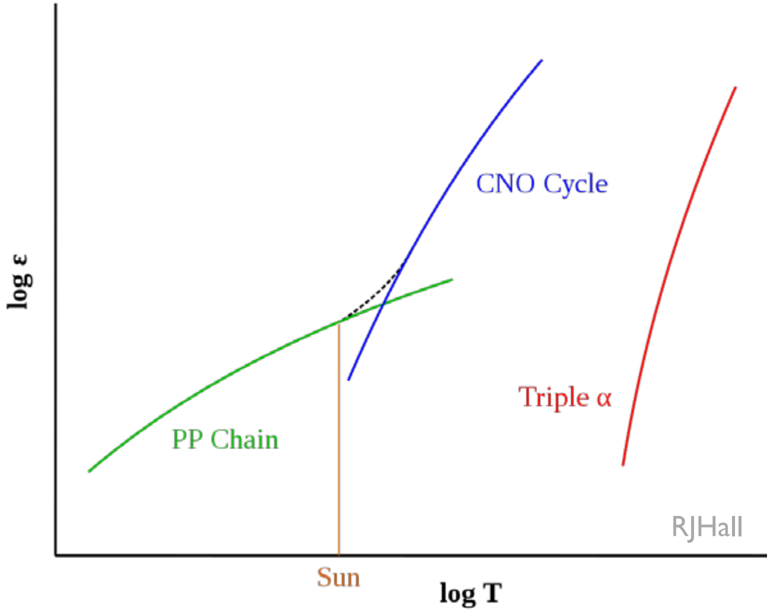


Core Helium Burning

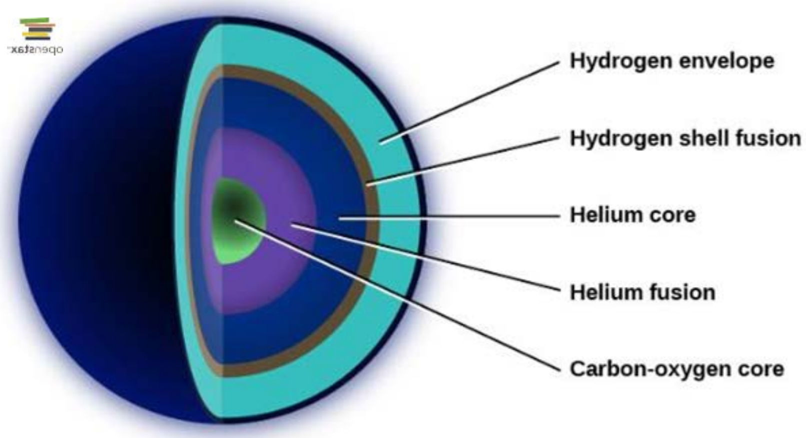
1. Eventually the core contracts enough and enough He is added, that core He ignites
2. With the core no longer contracting, the envelope is no longer puffed up. This **decreases the radius** and lowers the blackbody temperature. So **the star becomes a bit bluer.**
3. Since core helium burning can start for roughly the same core temperature and core helium mass, the **luminosity is roughly the same for stars at this point**.
4. The radius and blackbody temperature mostly depend on how large the remaining hydrogen envelope is, **so there is a spread in temperature**.

- This explains the "Horizontal Branch" on the HR-diagram
- Helium burning begins with the "triple-alpha" reaction (${}^{4}\mathrm{He} + {}^{4}\mathrm{He} + {}^{4}\mathrm{He} \rightarrow {}^{12}\mathrm{C}$), which has a much steeper temperature dependency than H-burning.
  This consumes fuel quicker and leads (along with shell H-burning) to a HB lifetime of ~1 to 100's of Myr



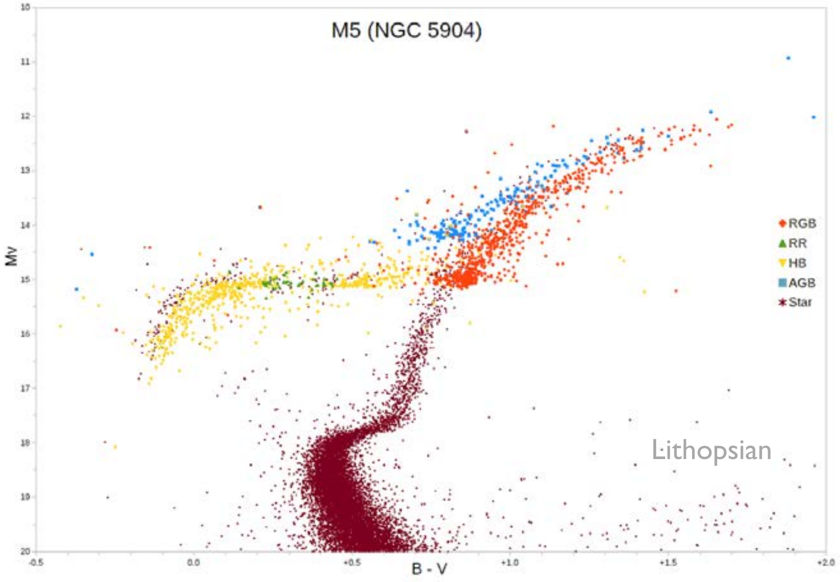


Shell helium (and hydrogen) burning

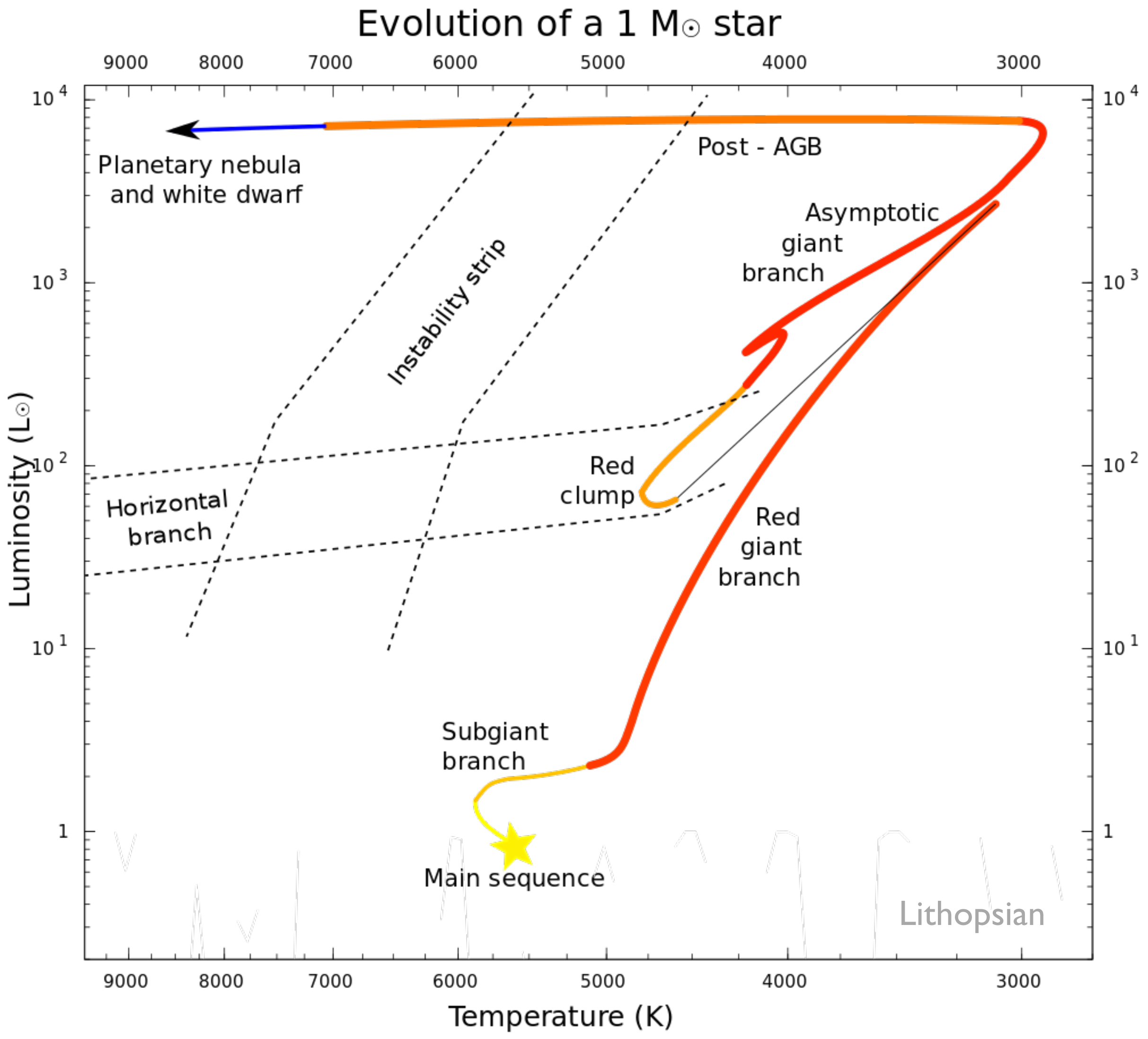


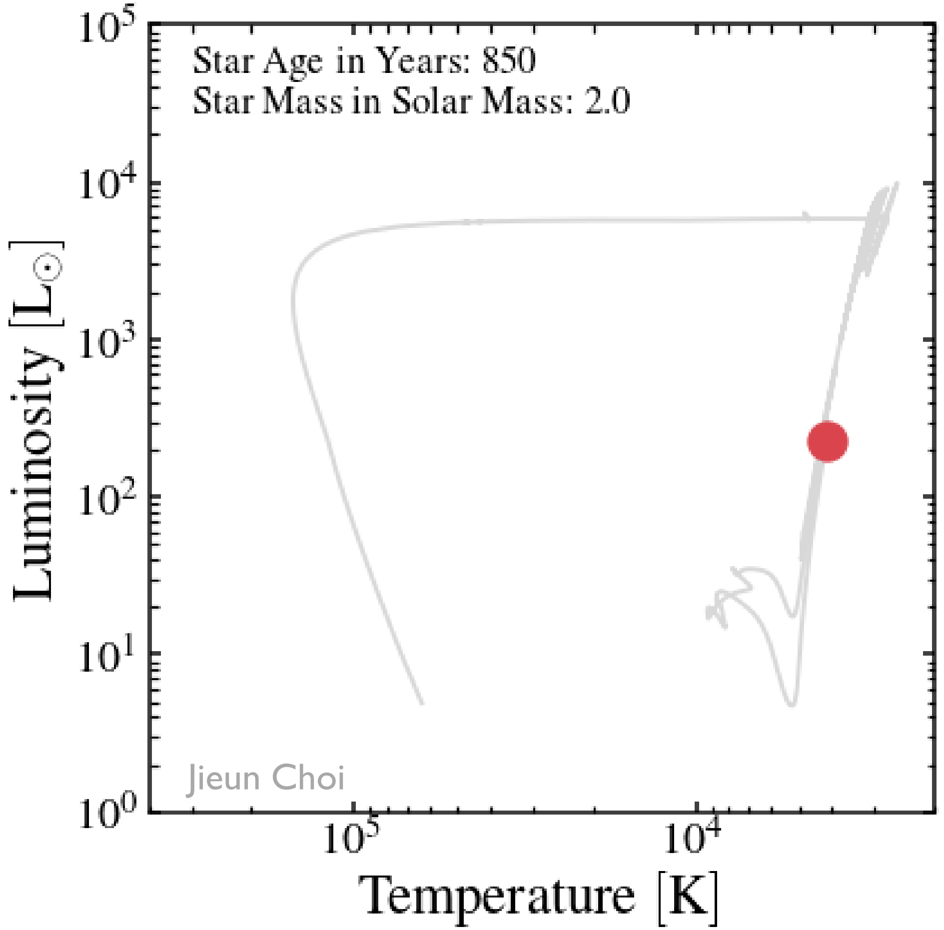
1. When core He runs out, the core (now made of C & O) steadily contracts and heats up
2. The He shell around the core can burn, releasing a lot of energy and adding C and O to the core
3. Because this shell He requires higher temperatures to burn, **the star's luminosity increases**
   (see Introduction to Stellar Nuclear Power)
4. Increased luminosity causes the outer layers to puff-up, **increasing the stellar radius** and therefore lowering the blackbody temperature. So, **the star becomes redder**

- This is how an "**Asymptotic Giant**" is made and explains its location on the HR-diagram
- Because of the higher luminosity and reduced amount of fuel, the time spent on the AGB is a few Myr



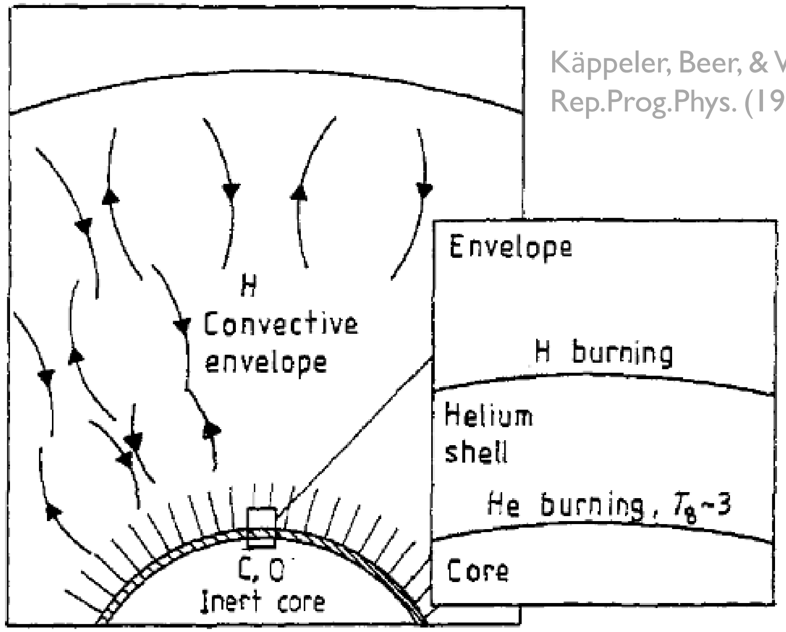
Low mass stellar evolution on the HR diagram



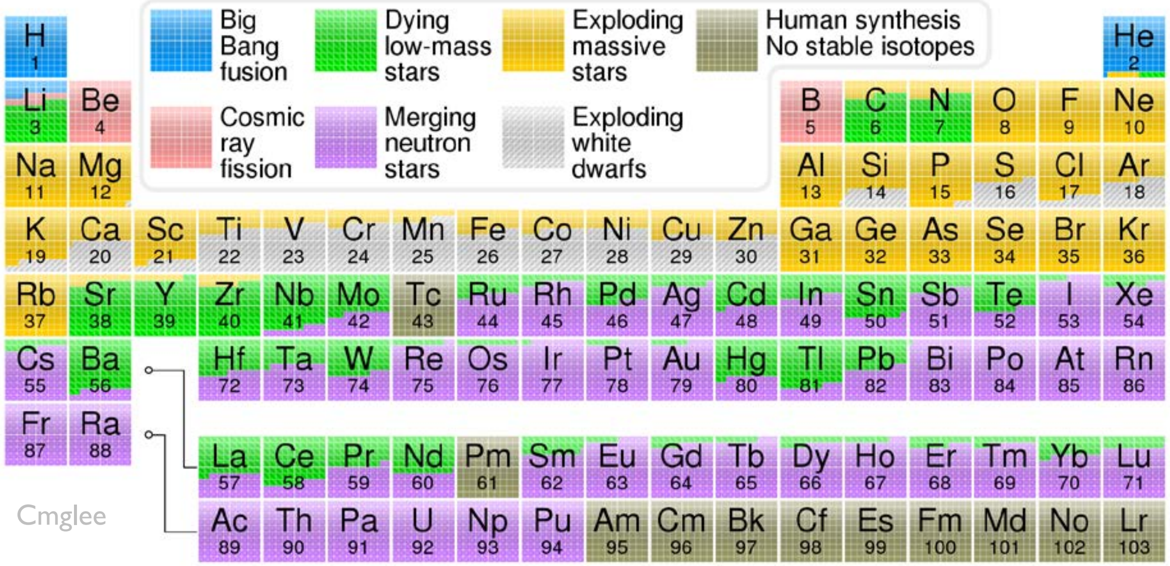


Low mass star nucleosynthesis

- Aside from the He, C, and O produced in stellar burning, heavier elements are made in the AGB phase
- Material from hydrogen and helium burning shells mix, causing significant neutron production
- Neutrons are captured by elements left behind from previous generations of stellar evolution, resulting in a nucleus capturing a neutron roughly each decade
- This slow neutron-capture process (“s-process”) is responsible for synthesizing a large fraction of the elements heavier than iron



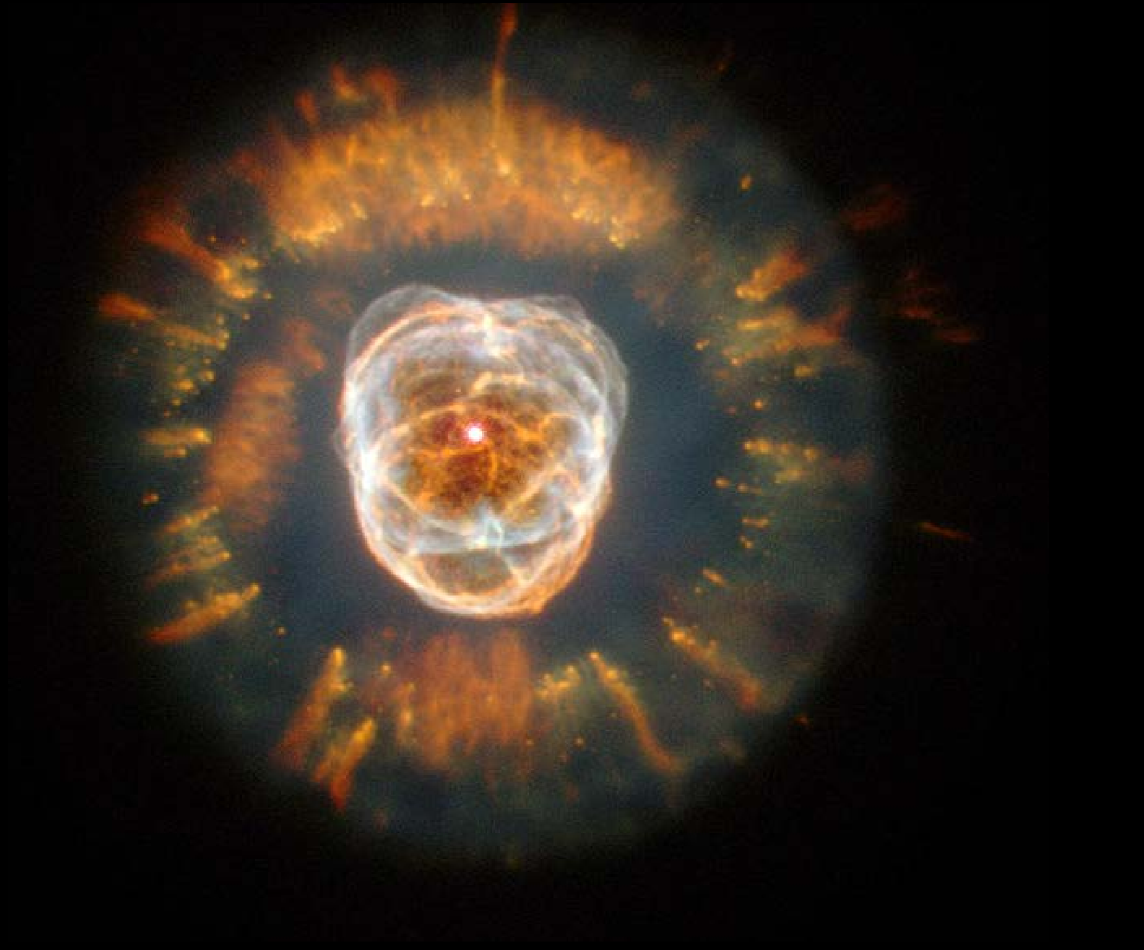
Käppeler, Beer, & Wisshak, Rep.Prog.Phys. (1989)



Cmglee

Chemical Enrichment from Low Mass Stars

- Gravity is weak near the surface of giant stars, so gas from the envelope can escape
- After core fusion ceases, the core is continually contracting and getting hotter
- Ultimately the radiation from the hot remnant (a white dwarf) at the center ejects the entire envelope of the star, producing a planetary nebula
- This injects the newly synthesized elements back into the galaxy to be included in future star formation
- These are only visible for ~50 kyr



STScI/NASA/ESA/ERO